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Stennis Space Center, MS 39529-5004

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Methane Hydrates DTAGS and Coring Cruise off the Carolina Coast

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From June 16 to July 19, 2002, NRL conducted a research cruise aboard the R/V Cape Hatteras out of Beaufort NC over the Cape Fear diapir and slide, and over the Blake Ridge diapir. High-resolution multichannel seismic data was acquired in all areas, and over the Blake Ridge diapir, a long baseline acoustic navigation system was used to colocate the seismic data with piston and gravity cores. Estimated accuracy of the colocation is 1 to 2 m. We report here exactly where and how the seismic and sample data were acquired.

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Abstract

From June 16 to July 19, 2002, NRL conducted a research cruise aboard the R/V Cape Hatteras out of Beaufort, NC over the Cape Fear diapir and slide, and over the Blake Ridge diapir. High-resolution multichannel seismic data was acquired in all areas, and over the Blake Ridge diapir, a long baseline acoustic navigation system was used to colocate the seismic data with piston and gravity cores. Estimated accuracy of the co-location is 1 to 2 m. We report here exactly where and how the seismic and sample data were acquired.

Introduction

The research cruise aboard the R/V Cape Hatteras to the Blake Ridge off the U. S. East Coast in June and July of 2002 was performed in support of NRL's current Accelerated Research Initiative in methane hydrates. Specifically, the region surveyed was intended to serve as a "type" area characteristic of a low-to-moderate fluid flux regime. During the cruise, DTAGS (deep-towed acoustics/geophysics system; Wood and Gettrust, 2002) data, gravity core, and piston core samples were acquired. Two areas were surveyed; the Blake Ridge diapir, and the Cape Fear slide. The Blake Ridge diapir is the southernmost in the string of diapirs which includes those in the headwall of the

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Cape Fear slide (Popenoe 1984, GLORIA, 1997), the largest modern slide in North America and one of the largest in the world (Figures 1 and 2). The Blake Ridge and Cape Fear diapirs deform the surrounding sediments which can then act as conduits for fluid flux, and thus a possible concentration mechanism for methane hydrates. This cruise was particularly notable because, for the first time, DTAGS data were co-located to within a meter or two with other measurements, namely piston and gravity cores, through the use of a long baseline (LBL) acoustic seafloor navigation system. The acoustic navigation and coring was performed only in the vicinity of the Blake Ridge diapir

In addition to the scientific objectives, the cruise also served as the field test for the new DTAGS, (the old system having been lost at sea in 1997). The data acquired over the Cape Fear diapir and slide were the first data acquired by the new system in the field. Beyond shot-point 2000 of the Cape Fear leg, a variety of tests were conducted using different towing speeds, acoustic waveforms, and acquisition parameters.

The chronology of events can be determined precisely from the data and tables but is synopsized here. The first step was deployment and calibration of the 4-transponder navigation array (e.g. Lindwall et al, 2003). Gravity cores were then acquired, along a line trending eastward off the crest of the Blake Ridge diapir. DTAGS was then deployed at the Cape Fear Diapir, where data were acquired and system performance tests administered. DTAGS was redeployed at the Blake Ridge diapir, where the transponder-navigated data were acquired. This was followed by a third deployment of DTAGS on the Blake Ridge crest where no data were acquired due to mechanical failures. In Beaufort the seismic and gravity core crew disembarked and the piston coring crew boarded. Using preliminary seismic sections from DTAGS in the transponder area as a

guide, over 20 piston core drops were performed, resulting in several methane hydrate samples. The transponder array was acoustically summoned to the surface and recovered upon conclusion of the piston coring.

DTAGS Survey Over the Cape Fear Slide and Diapir

Figures 2 and 3 show the ship track over the Cape Fear diapir and slide, beginning East of the diapir, progressing over the Ocean Drilling Program (ODP0 sites 991, 992, and 993, then turning northward over two diapirs still under the slide but too deep to exhibit a surface expression. The track ends well outside the slide in the area characterized by the low backscatter (dark shades) in the GLORIA (GLORIA, 1997) sidescan sonar images. Note that the shot numbers displayed correspond to the ship position, not the source position at the time of the shot. We expect the source to be 1-1.5 km behind the ship. The distance between the ship and source was not measured directly but can be estimated based on depth and length of cable out.

A monitor section of the DTAGS data over the Cape Fear diapir (Figure 4, enveloped signal), shows the entire record length for the near channel of each shot. The vertical striations throughout the section represent bad shots usually caused by errors in telemetry. Figure 5 shows the same data shifted in time such that the water bottom arrival time corresponds to the two way travel time for sound emanating from the sea surface, rather than from the source. Immediately apparent in the sediments surrounding the diapir is a prominent reflector 50-100 m below the seafloor, possibly representing the base of the Cape Fear slide.

Additional monitor sections, corresponding to the Northeast trending portion of the track (approximately shot-points 1000 to 2000) are shown in Figures 6 and 7. Again the data are shifted to show the data as a function of time from the surface in Figures 8 and 9. The bright sub-surface reflection continues throughout the section, well beyond the extent of the surface expression of the slide. It is unlikely that this reflection is due to gas because the expected depth to the base of methane hydrate stability in this water depth is greater than several hundred meters.

Transponder Navigated DTAGS Survey Over the Blake Ridge Diapir

Three East-West and one North-South lines were acquired over the Blake Ridge diapir (Figures 10 and 11). Line 4 passes directly over the crest of the diapir, and very near the ODP Site 996 Holes A-E. Gravity cores were acquired before the seismic data, but preliminarily processed data (not shown here) was used as a guide for piston coring, in an attempt to sample both close to and far from possible flux conduits imaged in the data.

Monitor sections of the Blake Ridge diapir area processed as in the Cape Fear area are shown in Figures 12-15. Note the interference of the sea surface arrival from shot-points 5050-5200, when the system was being towed shallow. During the Blake ridge portion of the cruise, the slip rings on the winch were bypassed in an attempt to reduce telemetry errors. This meant that data acquisition had to stop and the cable disconnected from the winch before the winch could be operated. Rather than risk degraded performance of the system after such an interruption, and because the interference of the sea surface arrival happened in a turn, away from the area of interest,

it was decided to allow the interference, knowing it would dissipate after the course straightened at about shot 5200.

The monitor sections show the bathymetric rise associated with the diapir, and possibly a wipeout, or blank zone at the crest of the diapir on line 4 at about shot-point 4165. Throughout the remaining region, sedimentary reflections are visible down to about 0.2 s two-way travel time, or about 170 m depth below sea floor.

The Seafloor Transponder Constellation

The transponders in the long base-line (LBL) navigation array were programmed to listen at 12.5 kHz and respond at a unique frequency (Table 1). A computer in the ship's lab drives the interrogating, hull-mounted transducer at 12.5 kHz, and listens using the same transducer to the incoming responses. Relay times from each element of the array are computed, allowing determination of position. Each transducer was mounted 8 m above a weight or monument, and about 8m below a series of floats. At the end of the experiment a programmed acoustic signal released the transponders from their anchor weights and they were recovered after an approximately 30 minute trip to the surface.

The original seafloor deployment was designed to space the array elements at a distance equal to about 1.5 times the water depth. Some difficulty was encountered communicating with the array, presumably due to the strength of the signals. One of the transponders (in the northwest corner) was found to be defective, brought up, repaired, and redeployed somewhat closer to the center of the array to reduce the distance and increase the signal strength. We also noted poorer communication when the ship was headed into the seas (southeast), presumably due to bubbles entrained below the hull

interfering with transmission and reception at the hull mounted transducer. However, because the instruments we were interested in locating were moving very slowly (about 1 m/s), interpolation between even intermittent fixes was expected to be accurate.

Merging Seismic and Navigation Data

Transponder navigation of the DTAGS tow-fish was acquired independently from the seismic data, so to get source and receiver positions into the SEGY headers, processed navigation was merged with the seismic data post-cruise. Additional editing of header values was required and included in this step. Because only 41 of 48 seismic channels and only 3 of 4 engineering nodes were present during acquisition, channel numbers, offsets, and depths for each channel required correction. The acoustic or imaging array extended for 18 channels, at 3 m spacing starting at 21 m. The geophysical array was 23 channels at 15 m spacing starting at 72 m offset, extending to 417m offset. The engineering nodes were located at offsets of 0, 132, and 282 m, and depths at receivers between the engineering nodes were linearly interpolated. Because the engineering node at the far end of the array was removed, depths of the receivers from 282 to 450 where linearly extrapolated using the dip of the streamer from 132 to 282 m offset.

The navigation processing required several steps, the first of which was a time shift of 2 minutes and 40 seconds so that the time stamps of the data and navigation were the same. Also, both the DGPS and acoustic navigation exhibited spurious values that were replaced. Most spurious navigation fixes were easily recognized because they required unrealistic ship and/or source speed, or were inconsistent with the length of

cable deployed. The few spurious DGPS fixes were removed and replaced with values linearly interpolated from non-spurious neighboring fixes. Acoustic navigation fixes at the source tow-fish were recorded every 10 seconds and the seismic shot interval was 30 seconds, but the intervals were asynchronous so interpolation between the fixes was required to assign a single position to the ship or tow-fish at every shot.

Because many of the acoustic fixes were spurious (sometimes many minutes would go by without a reasonable fix), the interpolation of the acoustic fixes was not linear, but rather based on the smoothed ship position which was accurately determined via DGPS, and the distances of the source behind the ship at the good fixes surrounding the spurious fixes. This technique avoided the segmented character of the track which would result from a simple linear interpolation of tow-fish position, and resulted in a much more likely position of the tow-fish, especially when the ship was turning. After the tow-fish positions were determined, the receiver positions were estimated assuming a straight streamer towing behind the tow-fish at the same angle as the tow-fish followed the ship (compass readings were not reliable). Thus an XY coordinate for each source and each receiver was determined.

All navigation files are in ASCII format and located on the CD with this report. The file; *allnav.asc* is the raw log of all ship and tow-fish, GPS and acoustic fixes. The file; *cfd.finalnav.asc* contains the edited navigation (shot number and ship location) for the data in and around the Cape Fear slide and diapir. The locations are latitudes and longitudes given in decimal minutes relative to the origin 75 degrees West and 32 degrees North. Some of the latitude minute values are larger than 60 and therefore represent positions north of 33 degrees. The file; *brd.finalnav.asc* contains the edited navigation

(shot number, ship location, and tow-fish location) for the data in and around the Blake Ridge diapir. The locations are latitudes and longitudes given in decimal minutes relative to the origin 76 degrees West and 32 degrees North. Because CMP binning is most easily done using Cartesian coordinates rather than geographical coordinates, the source and receiver positions in the SEGY headers of the data (not included in this report) are in units of centimeters from the origins given above.

Transponder Navigated Gravity Coring Over the Blake Ridge Diapir

The gravity cores were intended to sample the shallow sediments in a progression away from the crest for microbiological abundance and diversity. When each core was brought on deck, it was carefully subsampled with a syringe at 0, 2, 5, 10, 20, 40, and 80 cm from the seafloor. The volume of each subsample was about 10 cubic centimeters. Each sample was separately bagged, labeled, and frozen, and at the end of the cruise shipped frozen to Stennis Space Center for analysis.

The navigation transponder was attached about 4 m above the gravity core head, and removed as the core was brought up, and re-attached as the next core was deployed. Navigation fixes for the gravity cores where very noisy, but because the position changed very slowly during deployment and recovery, accurate positions of the sample could still be recovered. The acoustically navigated positions are located in Table 2

Transponder Navigated Piston Coring Over the Blake Ridge Diapir

Piston coring was successfully employed to recover samples of methane hydrate from within a few meters of the seafloor for radio carbon analysis at NRL in Washington,

DC. The acoustic relay used to locate the DTAGS tow-fish, and gravity corer was placed within one of two cylindrical holes in the head of the piston corer. The acoustically navigated positions are located in Table 3. Samples of methane hydrate were immediately isolated on deck and placed in liquid nitrogen for shipment.

Summary

Durring the June-July, 2002 research cruise aboard the R/V Cape Hatteras approximately 30 km of DTAGS data were acquired over the Cape Fear diapir and slide, and approximately 25 km of DTAGS data were acquired over the Blake Ridge diapir. In the Blake Ridge diapir area 12 gravity and 21 piston cores were were co-located with the seismic data using a long baseline acoustic navigation array. This work was funded by ONR program element 0601153N.

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DTAGS, Gravity Coring, Transponder Net

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Transponder Locations

xpndr	Deg. Lat.	Min. Lat.	Deg. Lon	Min. Lon	Depth (m)	Serial #	Freq. (kHz)
1	32	29.98261	76	10.88541	2177.7	15702	10.5
2	32	30.50290	76	9.884108	2192.4	15703	11.5
3	32	28.86641	76	9.872270	2202.9	14760	10.0
4	32	28.92300	76	11.46904	2164.0	15228	13.5

Table 1. The locations of the four transponders used in the BRD survey are given in degrees and decimal minutes. The depths refer to the actual depths of the transducers, not the monuments, or weights which rest 8 m below the transponders on the seafloor. The serial number is an identification number used by the manufacturer (Sonatech) to link each transponder to its characteristic response frequency. All transponders listen at 12.5 kHz.

Gravity Core Locations

Core	fix	June	GMT hr	min	sec	Ship Min. Lat	Position Min. Lon	Core Min. Lat.	Hit Min. Lon	Depth
c	221	26	23	2	49.7	29.608	9.4880	29.5703	10.2747	2192.41
d	56	26	21	24	5.9	29.544	10.012	29.5195	10.0389	1852.95
e	83	27	0	33	19.9	29.621	10.185	29.5281	10.2289	2143.53
f	277	27	10	42	27.9	29.633	10.390	29.6302	10.4093	2185.73
g	248	27	11	57	55.7	29.644	10.493	29.5591	10.5014	2200.51
h	218	27	13	17	2.3	29.658	10.840	29.6238	10.6098	2122.97
i	236	27	14	30	45.8	29.662	10.650	29.6121	10.7300	2064.35
j	286	27	15	48	15.5	29.764	10.753	29.6287	10.8140	2187.90
k	252	27	17	9	21.5	29.679	10.911	29.6271	10.8763	2192.80
n	184	27	22	1	37.9	29.610	11.135	29.5503	10.9773	2174.18
o	180	27	20	56	43.9	29.604	11.281	29.6428	11.3248	2179.27
p	118	27	19	44	5.7	29.560	11.417	29.5985	11.4327	2206.19

Table 2. Locations of gravity cores are given in decimal minutes north of 32 degrees latitude and west of 76 degrees longitude. Depths are acoustic readings at the corresponding fix number from the transponder clamped 4 m above the gravity coring head. The time at which the core hit the seafloor is also given.

Piston Core Locations

Core	fix #	July	Hr	min	sec	Ship Min. Lat.	Position Min. Lon	Core Min. Lat	Hit Min. Lon.	Depth
2	420	10	17	4	48.8	29.5120	11.4890	29.622	11.5183	2144.01
2.5	107	11	11	40	22.9	29.6280	11.5820	29.6515	11.5502	2141.14
4	299	11	14	57	2.7	29.5880	11.4710	29.6535	11.4867	2165.86
10	247	12	11	32	12.5	29.6130	11.3450	29.6261	11.3593	2095.08
11	213	12	14	7	35.9	29.6500	11.2980	29.6629	11.3238	2148.55
12	529	12	18	26	19.6	29.7080	11.3850	29.6617	11.3609	2009.73
13	213	12	21	22	27.7	29.6000	11.4560	29.605	11.4570	2086.51
18	256	13	11	40	41.6	29.6650	11.4700	29.5478	11.4357	2156.79
19	342	13	15	20	23.6	30.0360	11.1980	30.051	11.2366	2166.06
20	318	13	21	38	49.4	30.0110	11.6000	29.9678	11.6368	2161.47
24	252	14	11	46	51.7	29.9210	11.3000	29.5981	11.1150	1876.49
26	217	15	11	32	50.4	29.2073	9.4289	29.2587	9.3708	2193.12
27	145	15	16	26	25.9	29.2750	8.9000	29.6412	9.2312	1915.77
27.5	1	15	16	40	7.8	29.2070	8.9530	29.2678	8.9002	1700.65
28	272	15	19	25	47.5	29.5930	11.2440	29.6894	11.2764	2172.75
29	184	15	21	42	19.9	29.5750	11.3590	29.6547	11.3428	2154.01
30	340	16	11	32	31.6	29.5532	11.3245	29.6236	11.2982	2171.38
31	258	16	15	50	14.8	29.6428	11.3804	29.6675	11.3423	2173.95
32	244	16	21	27	13.5	29.6610	11.5280	29.6294	11.5210	2176.99
34	207	17	11	24	10.7	29.6420	11.4200	29.6698	11.4151	2170.12
36	263	17	15	19	6.9	29.6320	11.4410	29.6647	11.4264	2170.24

Table 3. Locations of piston core attempts are given in decimal minutes north of 32 degrees latitude and west of 76 degrees longitude. Depths are acoustic readings at the corresponding fix number from the transponder located within the piston coring head. The time at which the core hit the seafloor is also given.

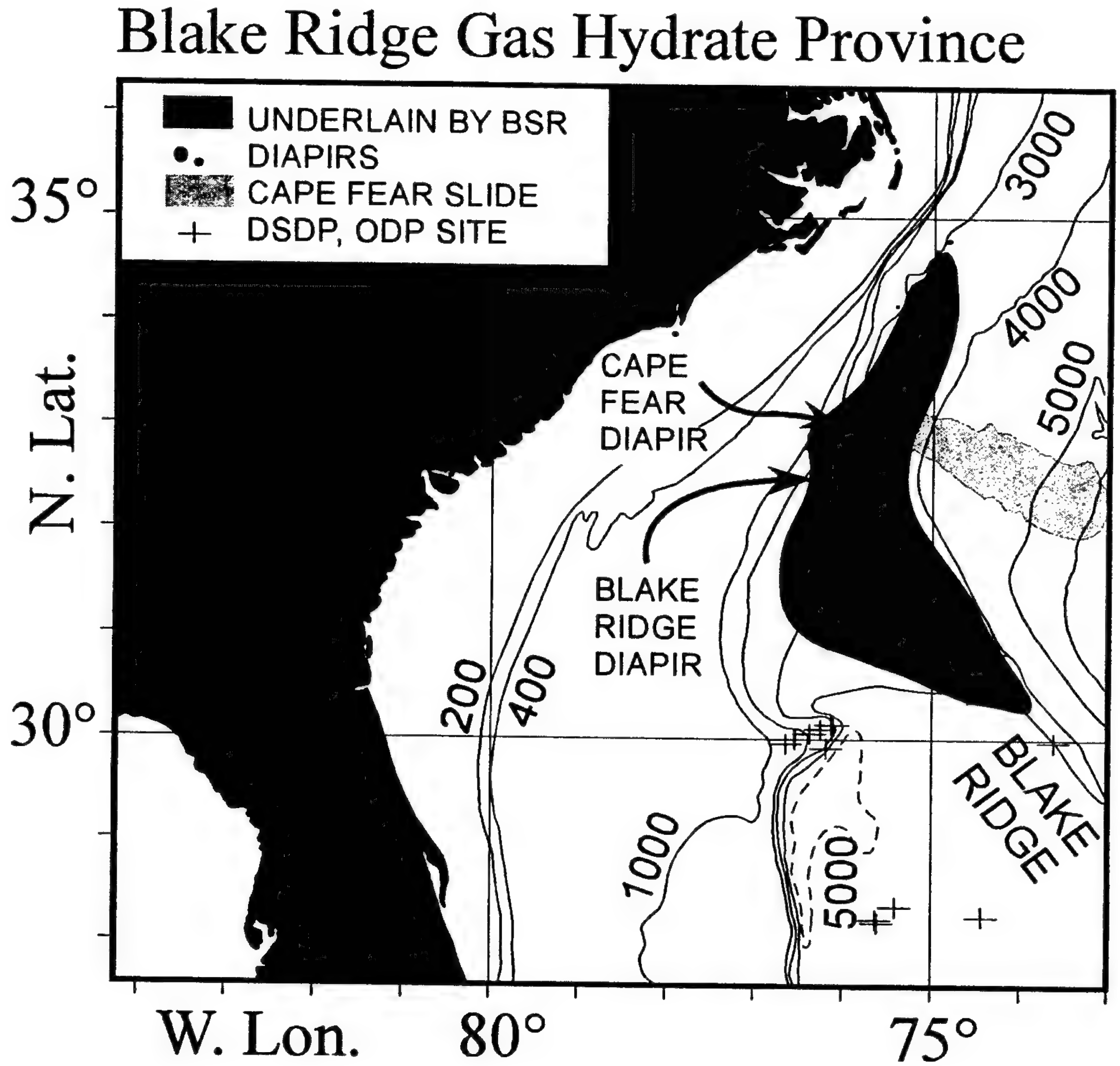


Figure 1. Methane hydrates in the Blake Ridge off the East Coast of the U. S. have been studied extensively via drilling and reflection seismic profiles. This large hydrate province also includes a string of diapirs along its western edge, that are very likely locations of concentrated fluid flux and hydrate accumulation. The 2002 Blake Ridge (br02) cruise covered targets in and around the Blake Ridge diapir as well as the Cape fear diapir located within the headwall of the Cape Fear slide.

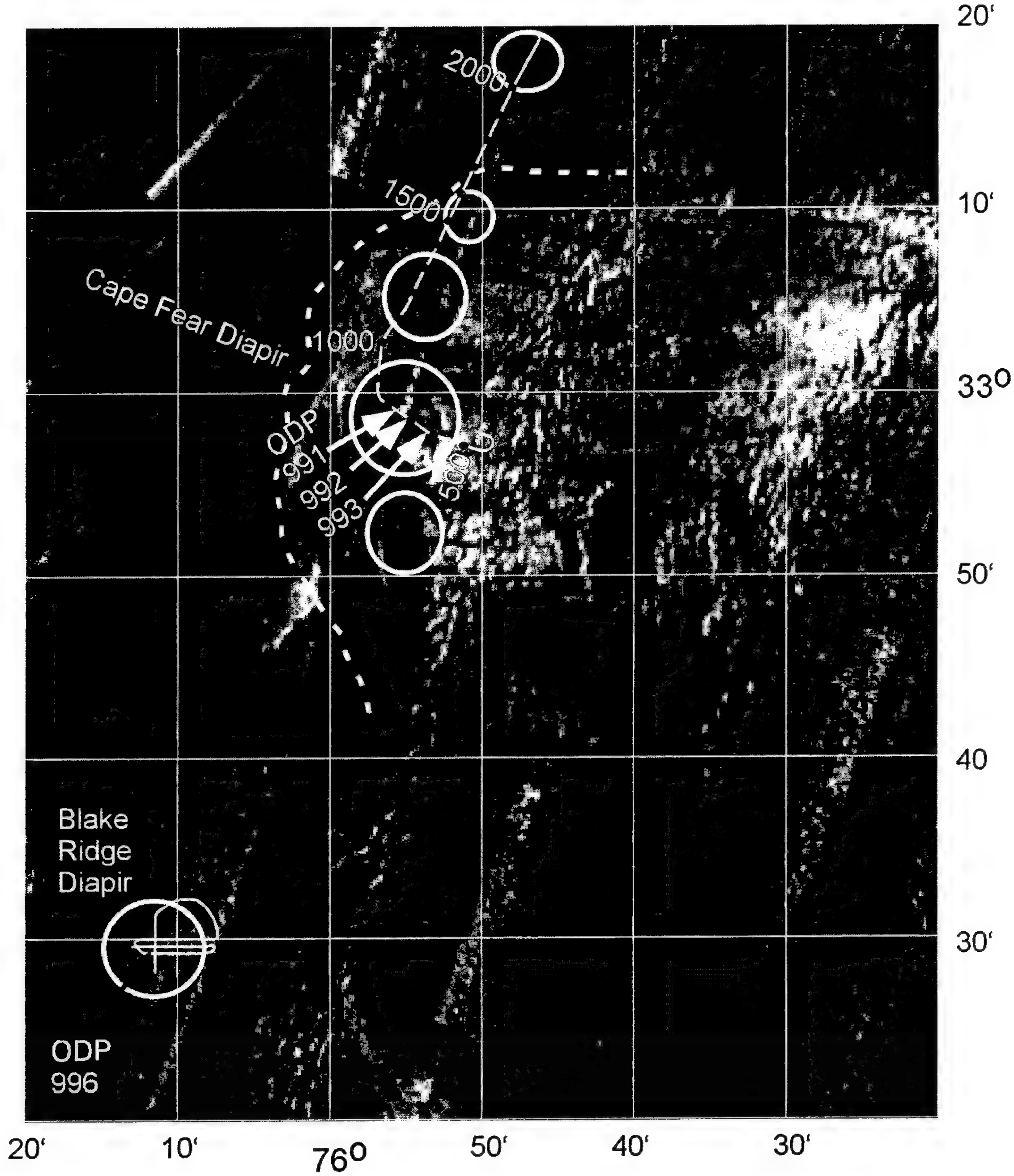


Figure 2. The first portion of the cruise covered the Cape Fear Slide and Diapir. White circles approximate the extent of subsurface diapirs (after Popenoe et al. 1984). Numbers are shot point numbers and are plotted at the ship position at the time of shot. Arrows indicate ODP sites 991, 992 and 993 from Northwest to Southeast, and the dashed line indicates the interpreted head wall of the Cape Fear slide. The slide material exhibits higher backscatter, shown as lighter shades in this sidescan image from the USGS's GLORIA data. The second portion of the cruise was spent acquiring transponder navigated DTAGS data in the vicinity of the Blake Ridge Diapir (lower left) where the third portion of the cruise acquired transponder located piston cores.

Cape Fear Diapir

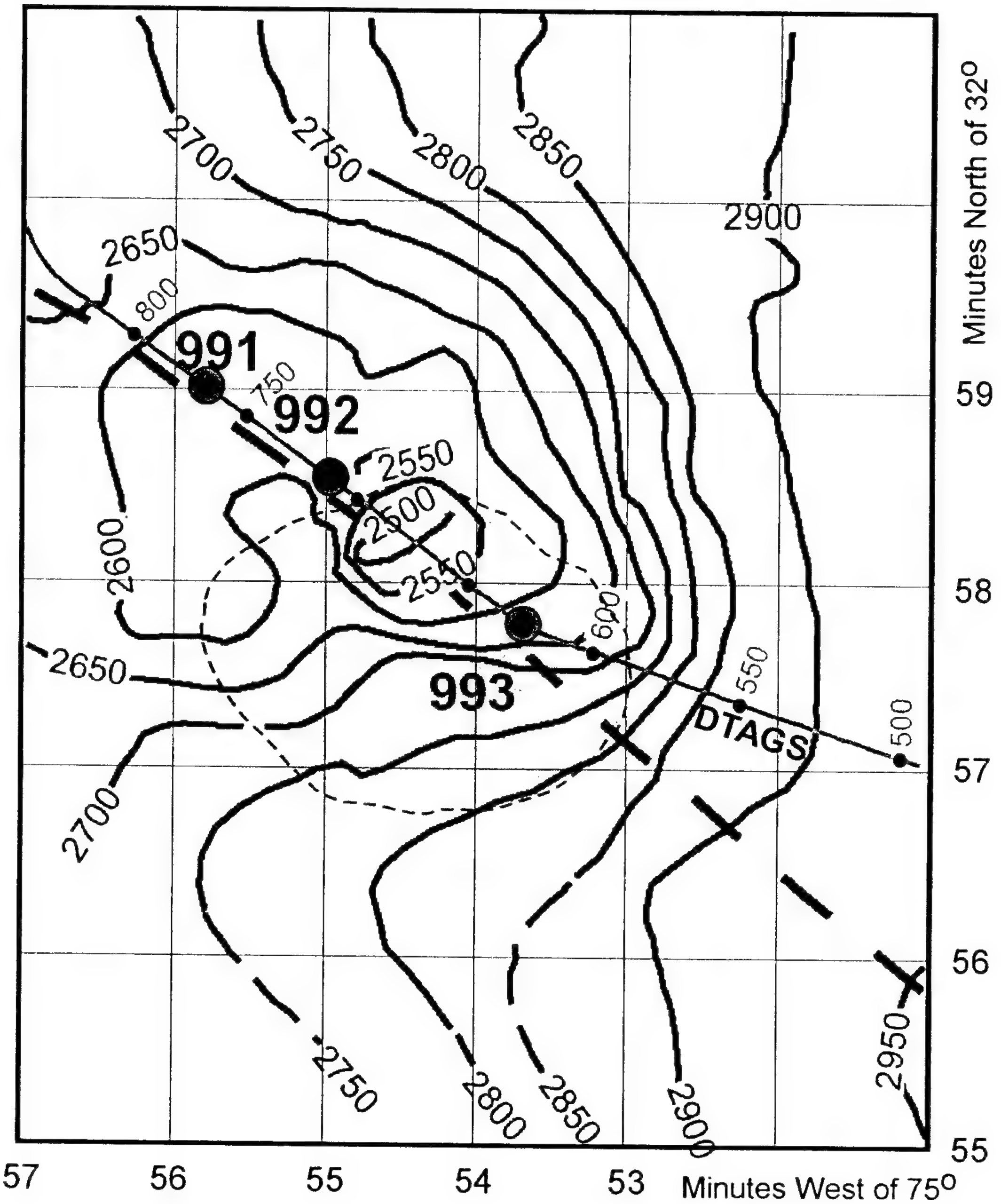


Figure 3. The crest of the Cape Fear diapir (The fine dashed line marks the sub-surface extent) has been examined via a surface towed seismic reflection profile (heavy dashed line) and an ODP drilling transect (gray circles), and now DTAGS (gray line). The gray numbers indicate ship position at the shot points; the towfish position is estimated to be approximately 1.5 km behind the ship. The contours are in meters.

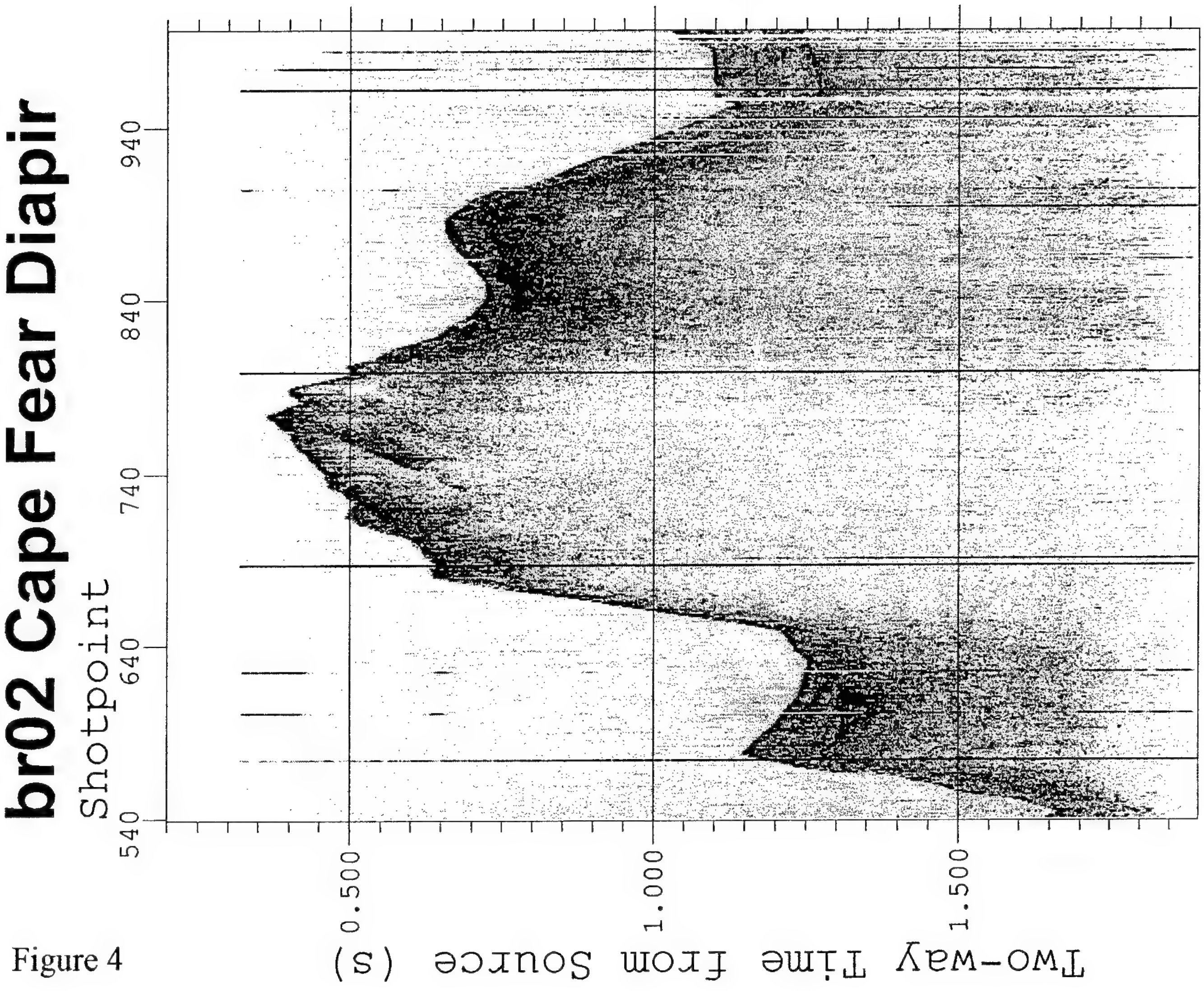

br02 Cape Fear Diapir
Shotpoint
540
640
740
840
940
0.500
1.000
1.500
Two-way Time from Source (s)

Figure 4

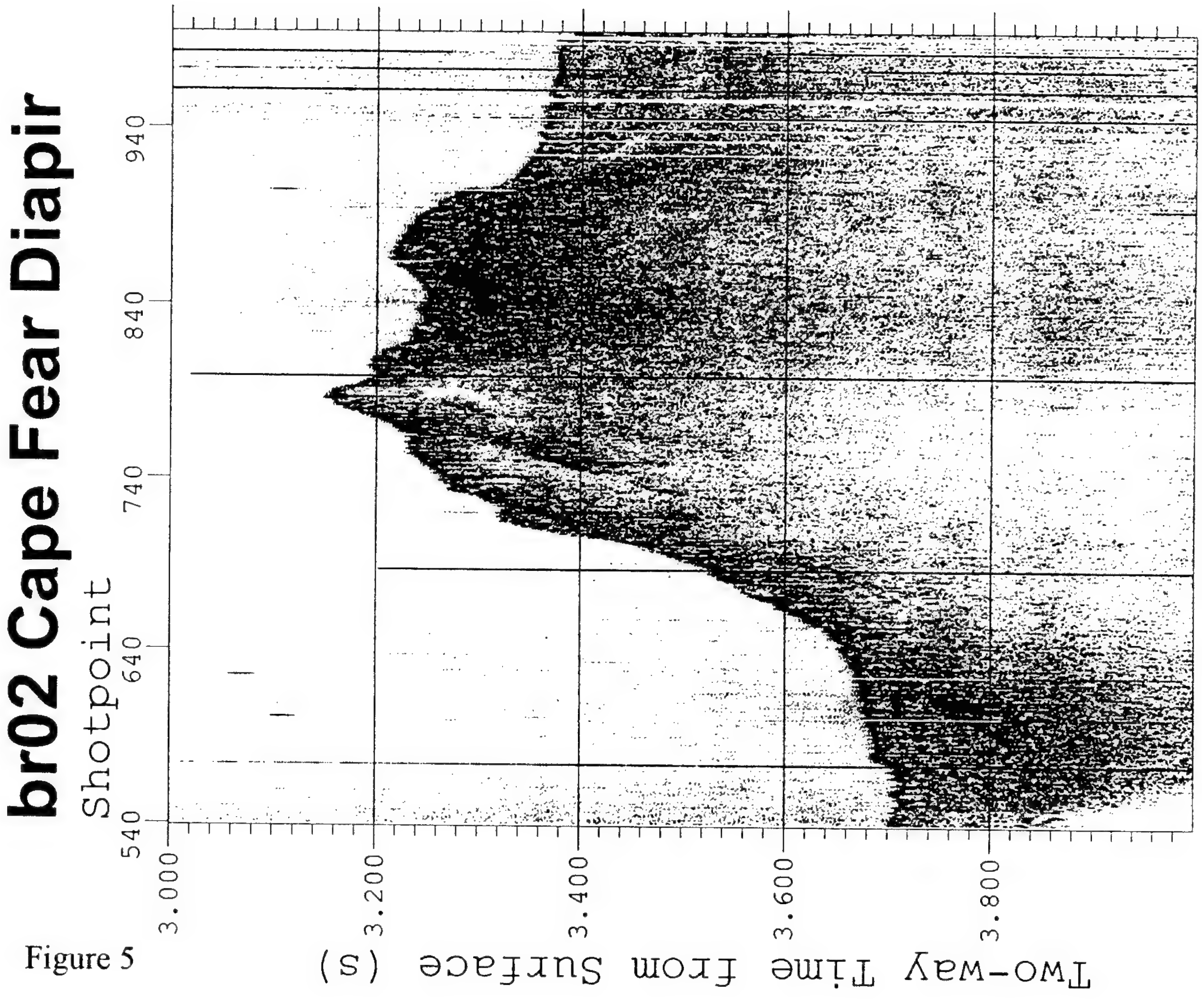
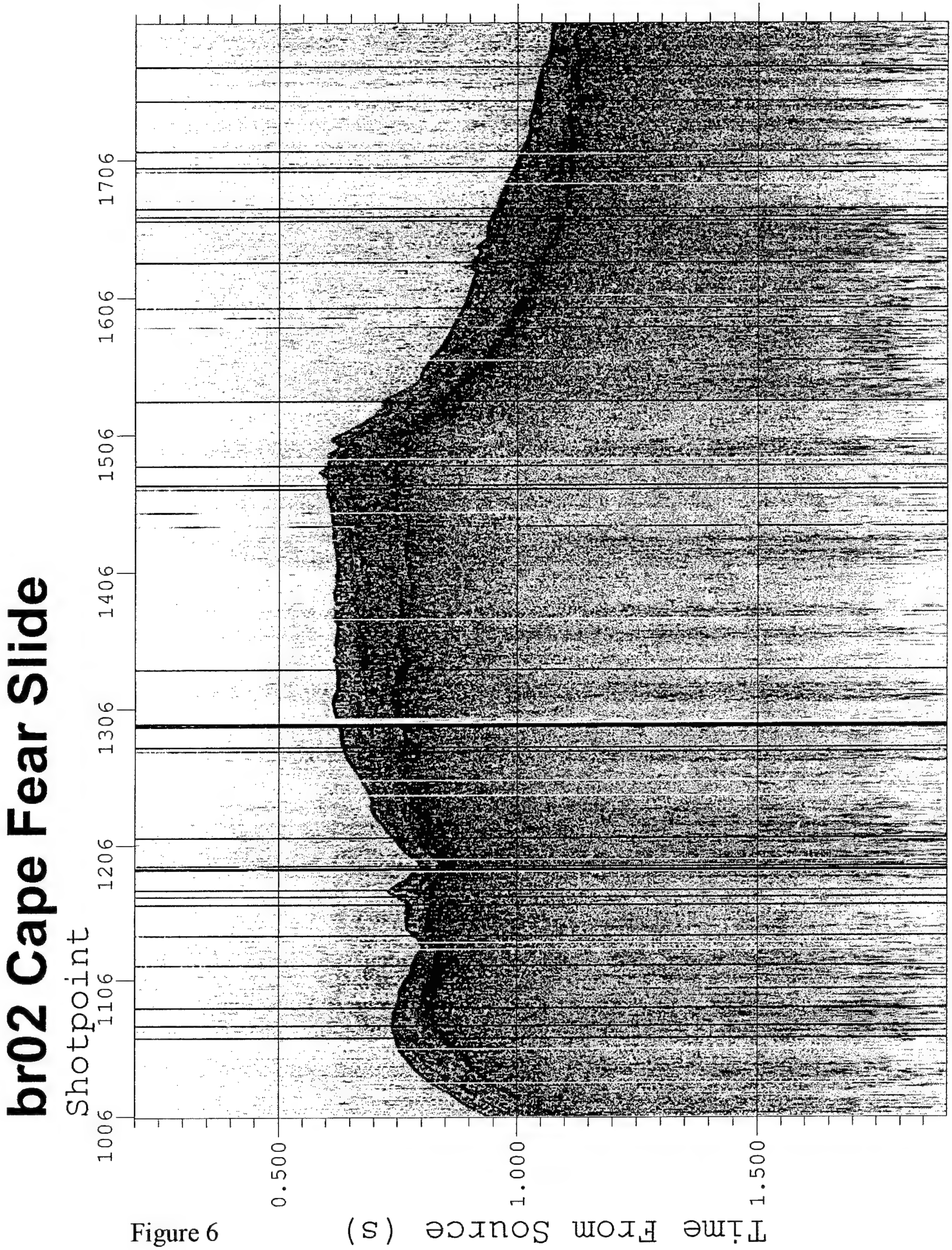
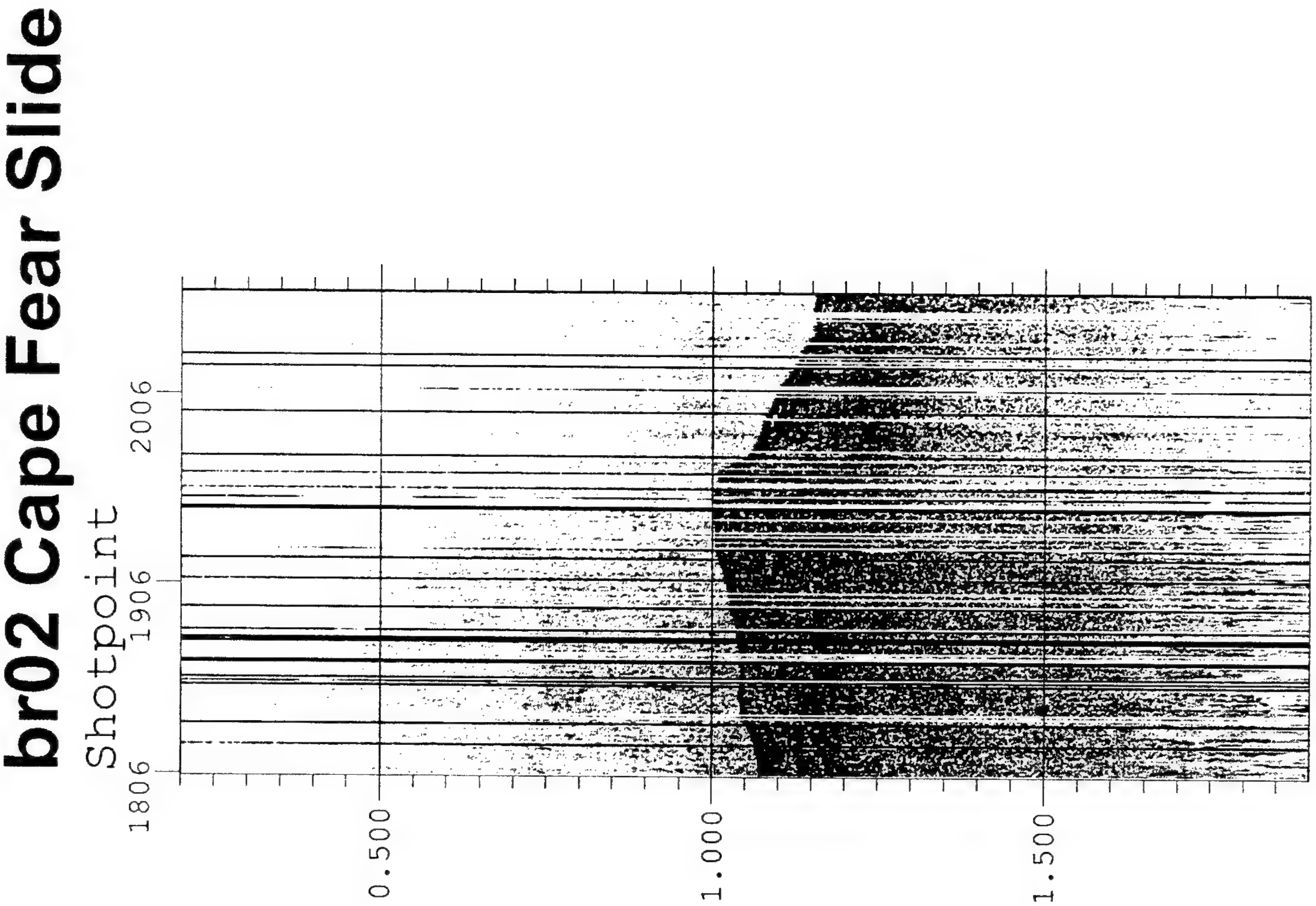


Figure 5



br02 Cape Fear Slide
Shotpoint
1006
1106
1206
1306
1406
1506
1606
1706
0.500
1.000
1.500
Time From Source (s)

Figure 6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Shotpoint
1806
1906
2006
0.500
1.000
1.500
Time From Source (s)

Figure 7

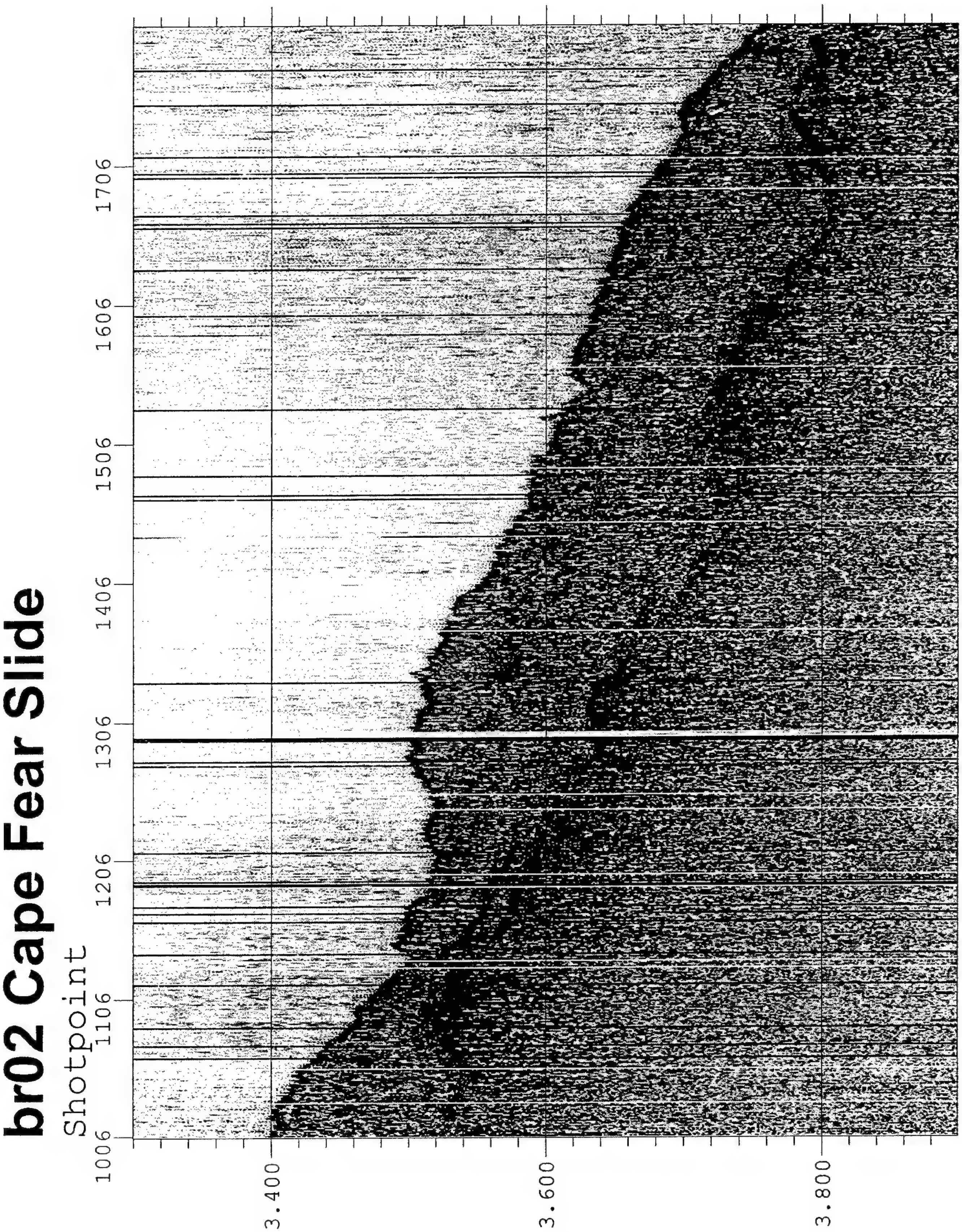
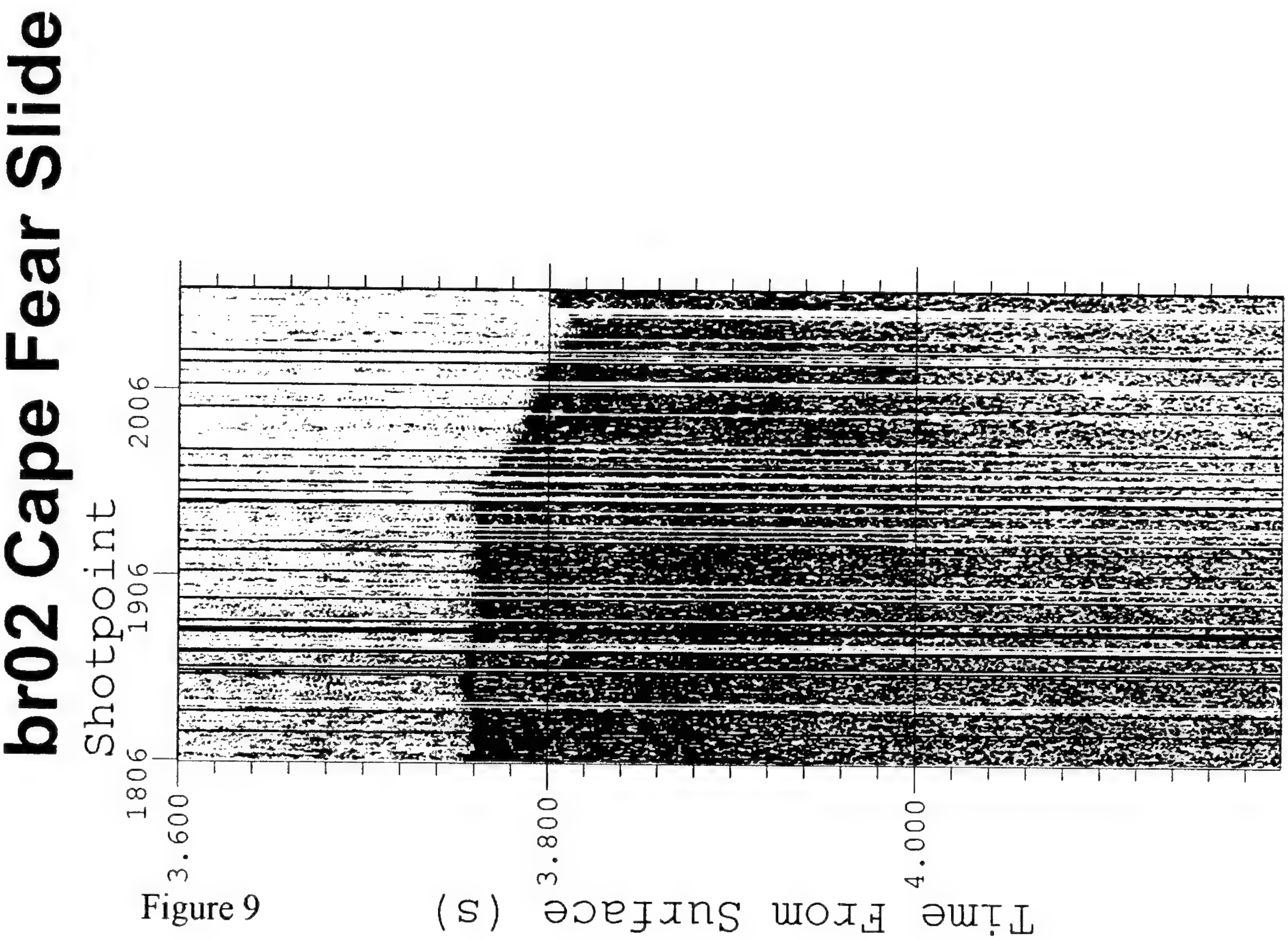

br02 Cape Fear Slide
Shotpoint
1006
1106
1206
1306
1406
1506
1606
1706
3.400
3.600
3.800
Time From Surface (s)

Figure 8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Shotpoint
1806
1906
2006
3.600
3.800
4.000
Time From Surface (s)

Figure 9

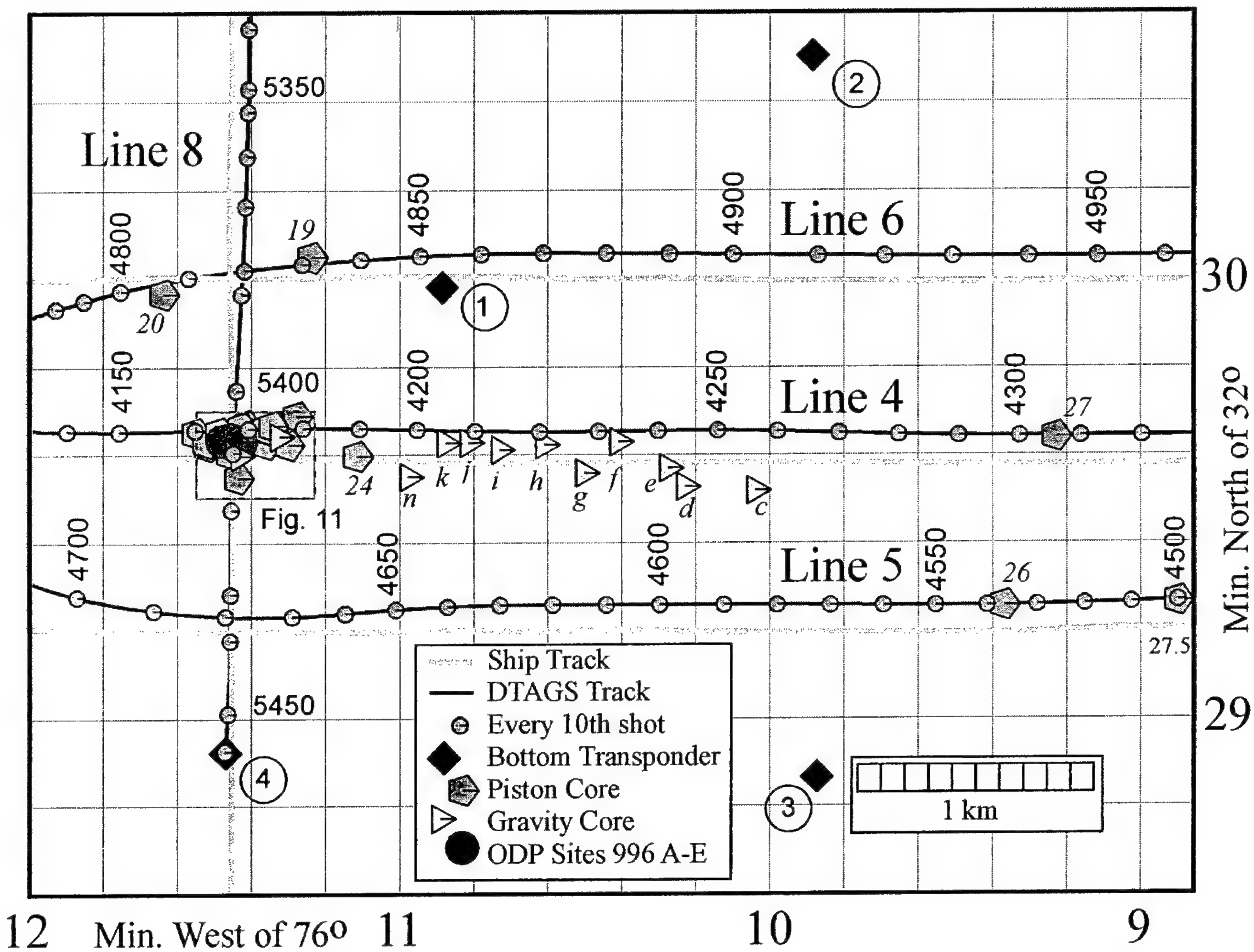


Figure 10. Blake Ridge diapir DTAGS and coring survey. Acoustic navigation transponders labeled 1-4, allowed accurate navigation (+/- ~1-2 m) of both DTAGS and cores. Strong surface currents were responsible for the large distance (>100m) between ship (light gray) and towfish (dark gray) tracks. Numbers and letters indicating piston and gravity cores, respectively are in italics.

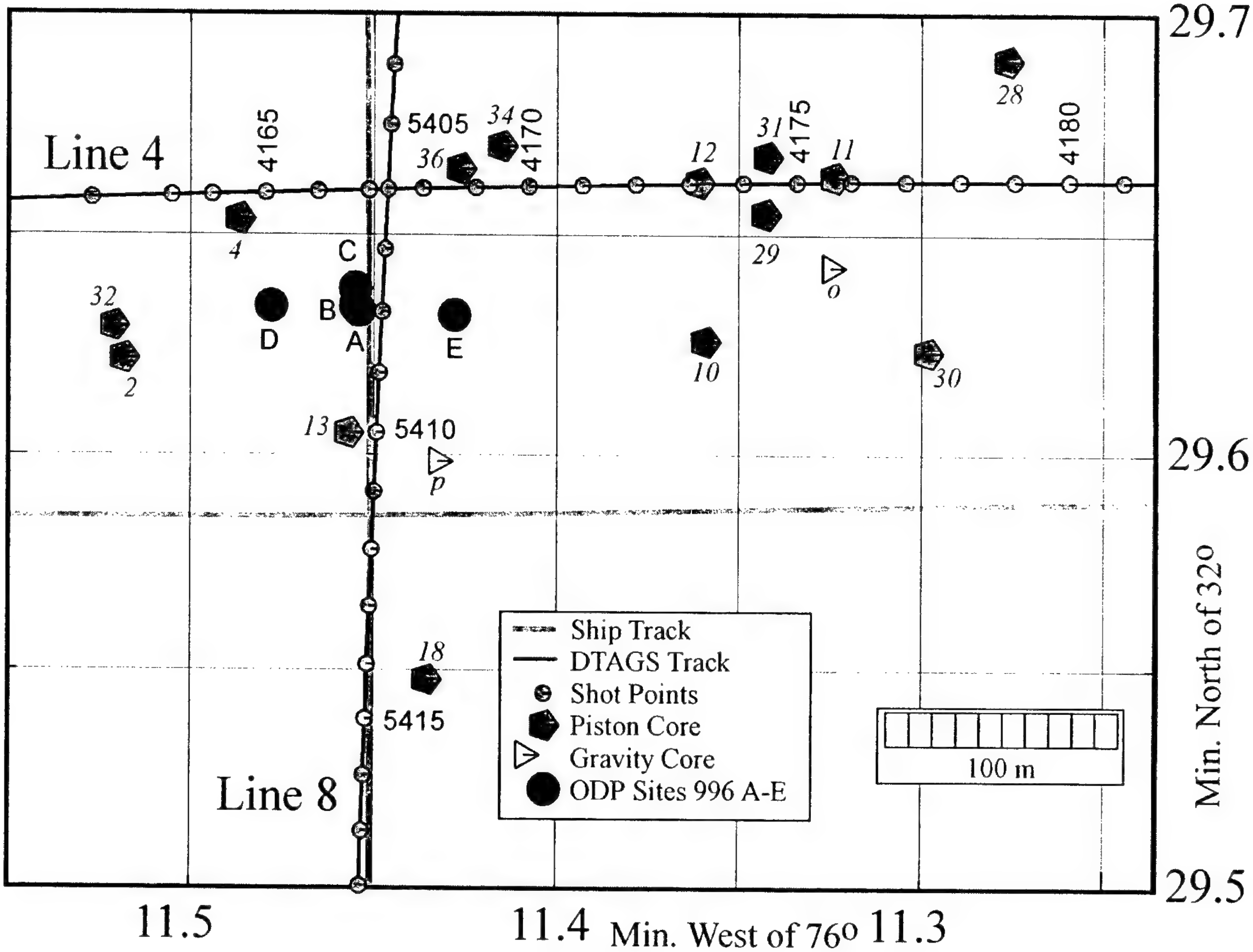


Figure 11. An expanded view of the data at the crest of the Blake Ridge diapir shows that the source tow-fish track (dark gray) lies about 50m north of the ODP site 996 transect. Shot 5408, however, lies within 10-15 m of holes A, B, and C. Numbers and letters indicating piston and gravity cores, respectively are in italics.

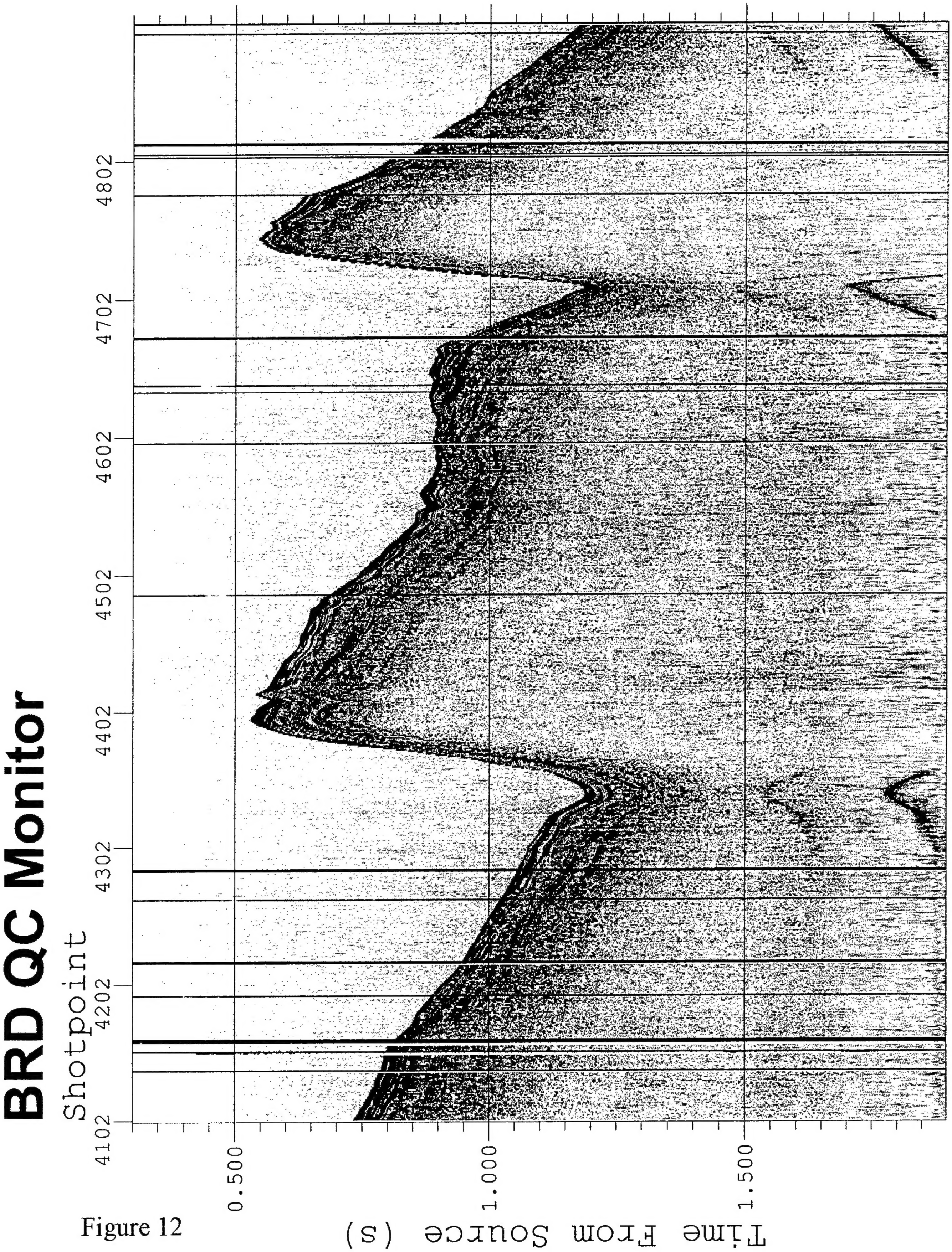

BRD QC Monitor
Shotpoint
4102
4202
4302
4402
4502
4602
4702
4802
0.500
1.000
1.500
Time From Source (s)

Figure 12

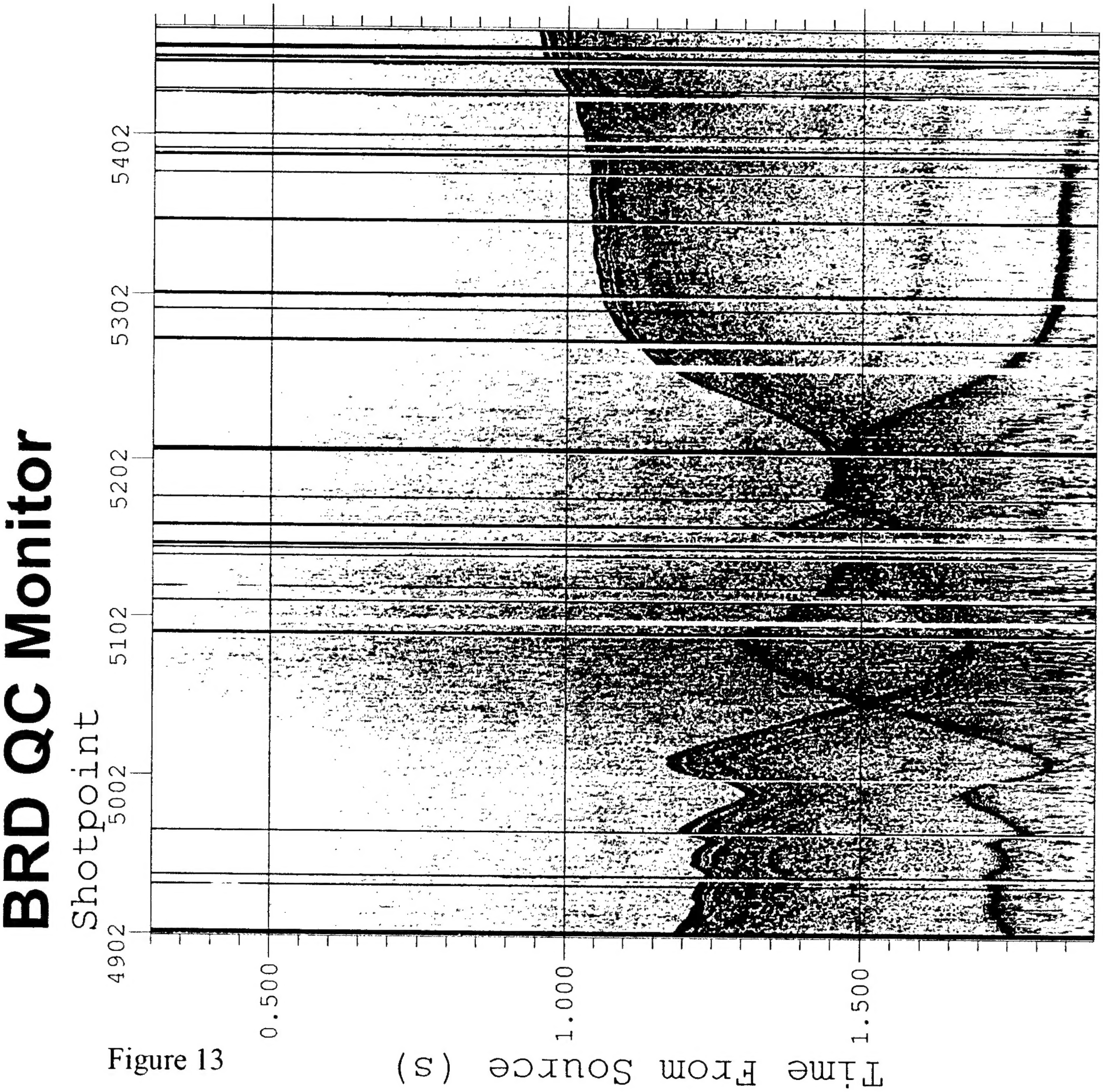

BRD QC Monitor
Shotpoint
4902
5002
5102
5202
5302
5402
0.500
1.000
1.500
Time From Source (s)

Figure 13

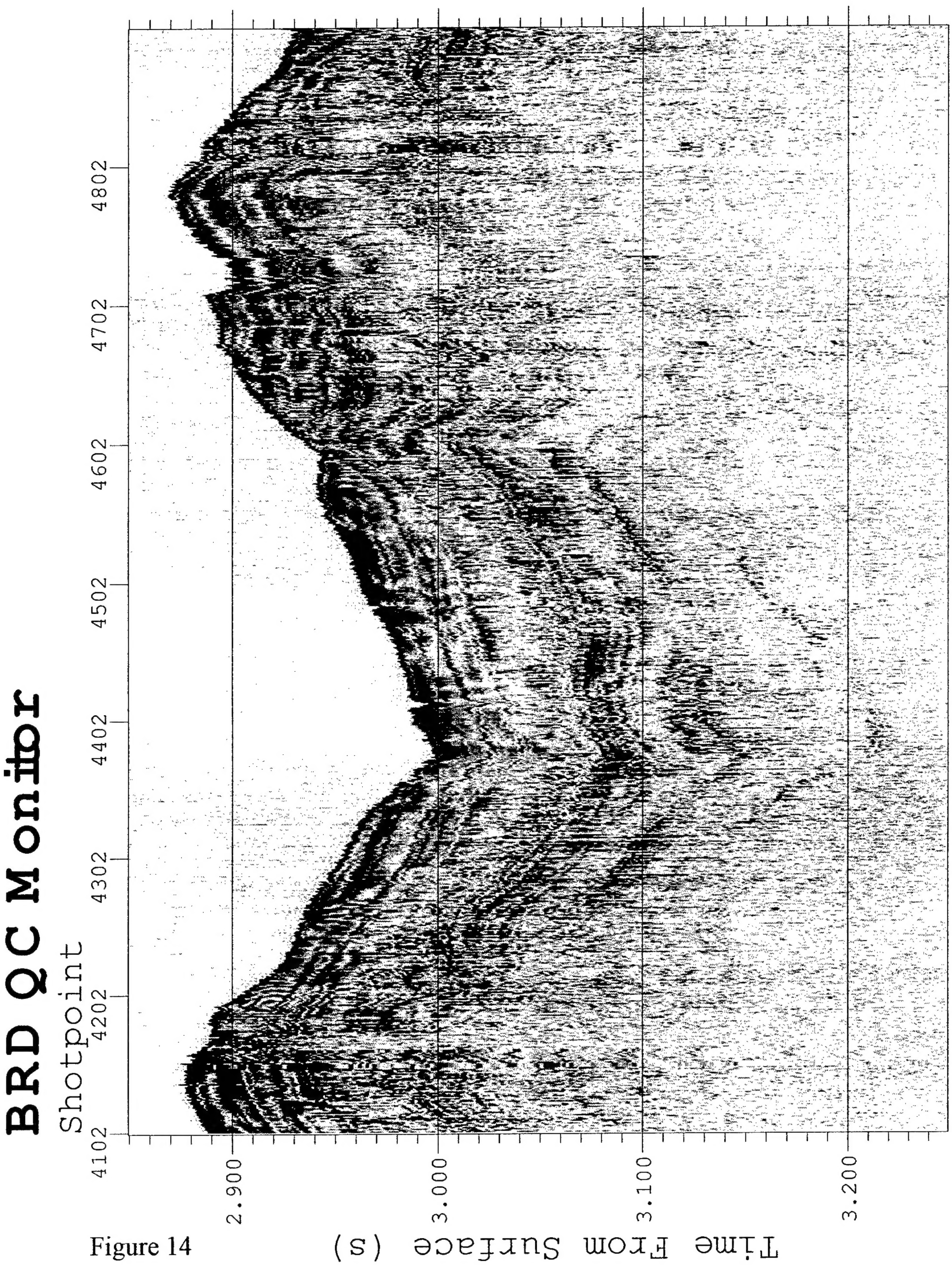
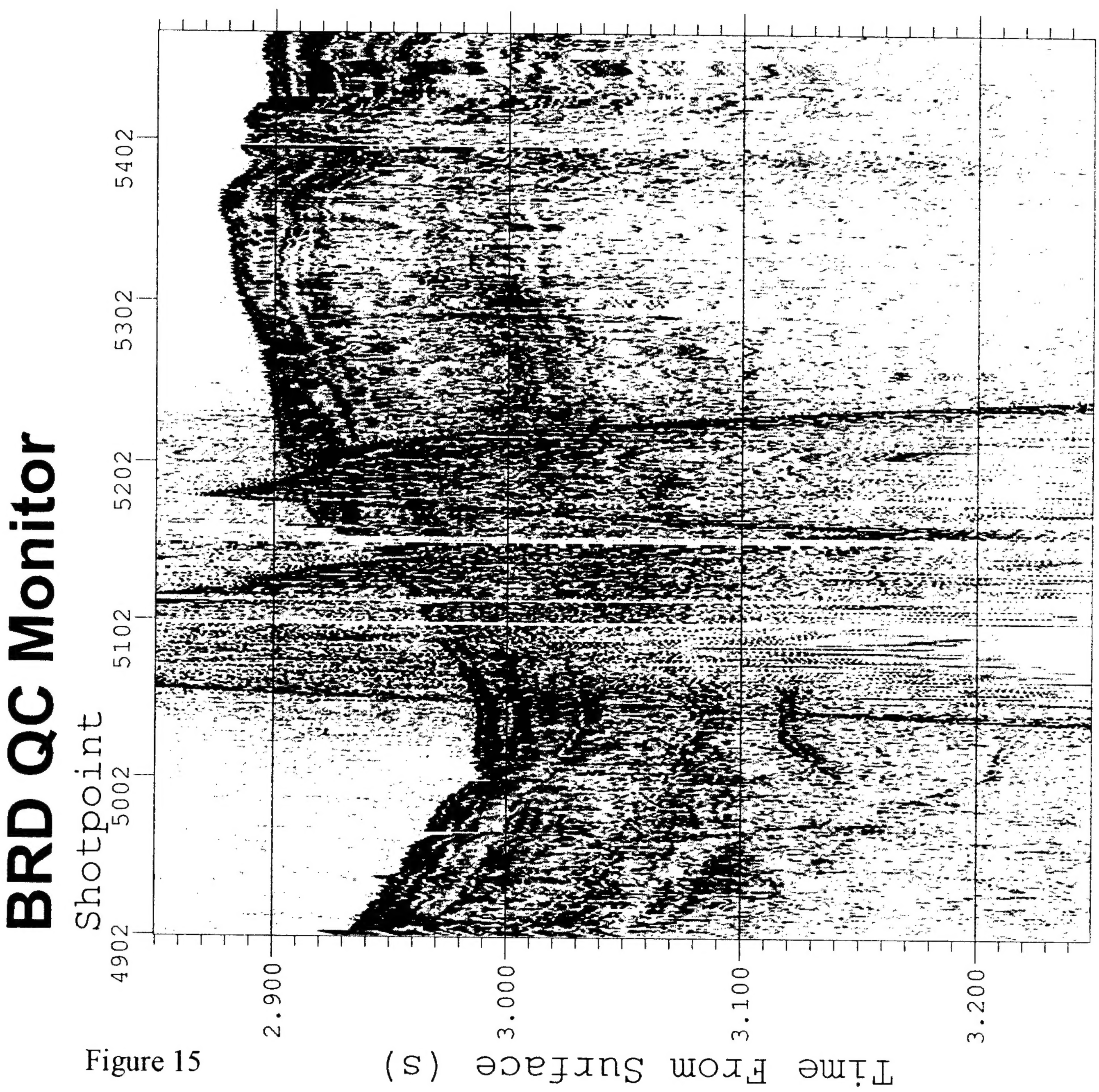

BRD QC Monitor
Shotpoint
4102
4202
4302
4402
4502
4602
4702
4802
2.900
3.000
3.100
3.200
Time From Surface (s)

Figure 14



BRD QC Monitor
Shotpoint
4902
5002
5102
5202
5302
5402
2.900
3.000
3.100
3.200
Time From Surface (s)

Figure 15